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Assessing the performance and cost of Logistics Airfleet options

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THESIS

ASSESSING THE PERFORMANCE AND COST OF LOGISTICS AIRFLEET OPTIONS

by

Jack N. Law

December 2000

Co-Advisors: William R. Gates
Keebom Kang

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The Chief of Naval Operations (OPNAV) has directed a study to determine the proper airfleet to satisfy the Navy's future logistics needs. The sponsor of the study is OPNAV N78G, the Financial Management Office of OPNAV's Air Warfare Division. The goal of the study is to ensure effective and efficient resource allocation in building an airfleet that will satisfy future peacetime and wartime airlift demand. This thesis supports the OPNAV study by providing a tool for evaluating airlift fleet options on the bases of cost and capability. This decision support tool combines an aircraft assignment model, which determines fleet capability, with a Life Cycle Cost (LCC) model, which calculates the cost of acquiring and operating a given fleet of aircraft. The combined models allow decision makers to specify a fleet mix with desirable performance characteristics, calculate the cost of that fleet, and observe the financial and operational effects of changing either the makeup of the fleet or the acquisition schedule. The thesis combines deterministic and stochastic analysis of historical demand data to assess the demand for aircraft and the capabilities of a chosen fleet mix. The data provided by the sponsor do not include overseas missions; this limits the scope of the study, but does not detract from the methodology. Cost data from Navy and commercial sources are used to develop LCC data for the chosen fleet. The resulting methodology, taken as a whole, provides detailed insight into the effects that fleet mix changes have on airfleet performance and cost. The user can incorporate various priorities (low cost, high capacity, high flexibility) in the selection of a fleet mix and observe the impacts these decisions will have on fleet cost and performance.

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ASSESSING THE PERFORMANCE AND COST OF LOGISTICS AIRFLEET OPTIONS

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Submitted in partial fulfillment of the
requirements for the degree of

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ABSTRACT

The Chief of Naval Operations (OPNAV) has directed a study to determine the proper airfleet to satisfy the Navy's future logistics needs. The sponsor of the study is OPNAV N78G, the Financial Management Office of OPNAV's Air Warfare Division. The goal of the study is to ensure effective and efficient resource allocation in building an airfleet that will satisfy future peacetime and wartime airlift demand. This thesis supports the OPNAV study by providing a tool for evaluating airlift fleet options on the bases of cost and capability. This decision support tool combines an aircraft assignment model, which determines fleet capability, with a Life Cycle Cost (LCC) model, which calculates the cost of acquiring and operating a given fleet of aircraft. The combined models allow decision makers to specify a fleet mix with desirable performance characteristics, calculate the cost of that fleet, and observe the financial and operational effects of changing either the makeup of the fleet or the acquisition schedule. The thesis combines deterministic and stochastic analysis of historical demand data to assess the demand for aircraft and the capabilities of a chosen fleet mix. The data provided by the sponsor do not include overseas missions; this limits the scope of the study, but does not detract from the methodology. Cost data from Navy and commercial sources are used to develop LCC data for the chosen fleet. The resulting methodology, taken as a whole, provides detailed insight into the effects that fleet mix changes have on airfleet performance and cost. The user can incorporate various priorities (low cost, high capacity, high flexibility) in the selection of a fleet mix and observe the impacts these decisions will have on fleet cost and performance.

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I. INTRODUCTION

A. BACKGROUND

As the current logistics airfleet ages, the Navy is initiating the purchase of replacement aircraft. In the spring of 2001, the Navy will begin operating a new type of logistics aircraft, the C-40. The C-40 is the military variant of one of history's most successful commercial aircraft, the Boeing 737. The C-40 is the replacement aircraft for the C-9B, which entered service in the early 1970s. The Navy has already purchased five C-40s; these aircraft are expected to enter service over the next two years. Initial estimates indicate that the Navy plans to acquire a total of 27 to 29 C-40s.[1] The C-40 is not the only new logistics aircraft being purchased by the Navy. The C-35, a seven-passenger jet, and the C-37, a 19-passenger jet, are also in the acquisition plan.

The Office of the Chief of Naval Operations (OPNAV) Code N78G, the Financial Management office of the Navy's Air Warfare Division, is sponsoring research to determine the effective allocation of resources in building the Navy's future airlift fleet. Goals of this research include determining the airlift demand that the Navy is likely to face in the future and describing the fleet that will meet that demand. The OPNAV-sponsored research project will consider not only peacetime demand, but also the demand faced in the event of two nearly simultaneous major theater wars. This thesis supports the OPNAV study by providing a method to assess the capabilities and costs associated with a given fleet of aircraft.

[1] Interview with CDR Rey Consunji, USNR, Commander Naval Air Reserve Force (CNARF) C-40 Program Manager, 27 September 2000.

B. PURPOSE

This study provides Navy decision makers with a tool for evaluating airlift fleet options on the bases of cost and capability. The decision support tool combines an aircraft assignment algorithm, which determines fleet capability, with a Life Cycle Cost (LCC) model, which calculates the cost of acquiring and operating a given fleet of aircraft. Combining the models allows the decision makers to construct a fleet with desirable performance characteristics, calculate the cost of that fleet, and observe the financial and operational effects of changing either the makeup of the fleet or the acquisition schedule.

C. SCOPE AND METHODOLOGY

This study provides insight into the effects of fleet mix on airlift capability. The data used to develop the model and evaluate the fleet options are limited to Navy airlift requests for missions originating and/or terminating in the continental United States (CONUS). The data set is limited to CONUS missions because the research sponsor did not provide out of CONUS (OCONUS) mission data. Additionally, no forecast of wartime requirements was made for this study. However, the model is easily adaptable and can be used for analysis should a broader data set become available. This report, therefore, is more suited to demonstrating a methodology for fleet analysis than to providing specific recommendations for currently pending decisions.

The first part of the study (Chapter II) demonstrates a static assignment algorithm. The assignment algorithm analyzes the characteristics of the lift requests and determines which aircraft type would be the best choice to carry the lift. The algorithm uses assignment assumptions that fit the typical practice of the Navy Air Logistics Office

(NALO), although NALO procedures have a significant amount of variation and can't be consistently modeled for all lift requests. The static fleet mix assignment algorithm produces the ideal assignment for all lifts. The model also describes the characteristics of a representative set of demand.

The lift characteristics generated by the static model provide input to the stochastic fleet mix model (Chapter III). The stochastic model uses Monte Carlo simulation to accomplish roughly the same process described in the previous paragraph. Variations in lift distance and number of lifts assigned create uncertainty in aircraft flight time requirements; this uncertainty, in turn, creates variations in the required fleet mix. The model provides probabilistic information concerning the likelihood that a given fleet will meet the desired performance parameters. The user can easily manipulate the fleet mix or aircraft performance parameters to see how these elements affect fleet performance. The stochastic model gives the user the ability to generate different fleet composition options that satisfy different priorities.

The third model introduced in the study is the LCC model (Chapter IV). Fleet options developed in the previous section are plugged in to the LCC model. The LCC model uses cost data gathered from military and commercial sources to calculate the LCC for each fleet option. Commercial data are used because the Navy does not yet have consistent, reliable data regarding the acquisition or operating costs of the new aircraft types. The main parameter of interest is the Equivalent Annual Net Cost (EANC); the EANC method produces a LCC result that is both realistic and comparable among all fleet options. The LCC model includes a feature that allows the procurement schedule to

be adjusted, thus capturing the effects of the time value of money and of continuing to operate older aircraft.

The next section of the study (Chapter V) puts all the models into action. First, the capabilities of the current fleet are determined using the static model; then the stochastic model is used to develop fleet options; these options become inputs to the LCC model. Analysis of the costs and capabilities of the options points out the tradeoffs associated with different fleet priorities.

In the final chapter, the value of the entire methodology is considered. The validity of the various models is examined in light of the models' assumptions and limitations. The results of the CONUS data analysis is discussed, but the more important assessment is whether the study provides a useful decision making tool. The utility of the models, as well as possible improvements, are discussed in this final chapter.

II. FLEET MIX SELECTION MODEL

A. INTRODUCTION

The Fleet Mix Selection Model generates what is called an "ideal fleet mix." This is a mix whose composition is most closely aligned with the types of missions being requested. In other words, if the demand contains a preponderance of requests to move large lifts, the mix will contain a greater proportion of large aircraft (C-40s and C-130s). Likewise, if the demand focuses on small, short lifts, the model will generate a fleet with more of the smaller aircraft (C-35s). While this process generates a fleet mix with maximum flexibility, it does not necessarily provide the only mix that will satisfy the demand, nor the cheapest. This process does favor maximum flexibility in aircraft assignment and minimum delay in satisfying lift requests. Tradeoffs among operating costs, acquisition costs, excess capacity, and flexibility will be discussed in Chapter V.

In addition to generating the "ideal fleet mix," the model allows the decision-maker to select different fleet mixes and compare their capabilities. This aspect of the model is useful in predicting the capabilities of fleets that focus on other priorities, such as lower acquisition cost or greater excess capacity.

This chapter focuses on information regarding the future fleet. The same model is used to determine fleet mix requirements with aircraft types in the current fleet. Analyzing the current fleet using the same model allows the decision-maker to observe the changes in capability expected by introducing new aircraft. Results of analyses of both the current and future fleets will be introduced in Chapter V.

The chapter is organized in the following format:

A. Introduction

B. The Assignment Algorithm

C. Predicting the Ideal Fleet Mix

D. Assessing the Capabilities of a Chosen Fleet Mix

E. Chapter Summary

B. THE ASSIGNMENT ALGORITHM

The first step in determining the appropriate fleet mix is to create a procedure for assigning lift requests to aircraft. The scheduling personnel at the Navy Air Logistics Office (NALO) and the Joint Operational Support Airlift Center (JOSAC) perform the real world equivalent of aircraft assignment. When scheduling aircraft for missions, the schedule writers have at their disposal real-time data to help optimize the use of aircraft. The myriad origins and destinations, use of priority codes, and attempts to combine lifts when practical are a few of the factors which increase the complexity of the assignment problem. While there are general guidelines that the schedulers follow, there is no comprehensive set of rules that can be adequately modeled within the scope of this thesis. Thus, the model used in this thesis will use common scheduling guidelines and practical assumptions to generate a reasonable primary assignment of a lift to a particular aircraft type.

1. Inputs to the Assignment Model

Four elements common to every lift request are used as the input data for the aircraft assignment model; the elements are origin, destination, passengers, and cargo. The four-letter International Civil Aviation Organization (ICAO) airport identifiers

represent the origin and destination; passengers and cargo are input as number and pounds, respectively.

The number of passengers (Pax) and pounds of cargo (C) are used in the model as separate variables and as components of "payload." It is standard NALO procedure to allow 200 pounds for each passenger (includes the person and luggage). Total payload (P) on a lift is calculated as in Equation 2.1.

$$P = (200 * Pax) + C$$

Equation 2.1. Payload

2. Constraints in the Assignment Model

Assignment of an aircraft type to a lift is constrained by the performance specifications of each aircraft. Table 2.1 is the specifications matrix used to assign aircraft for the future mix of the airfleet. Data in the performance matrix were provided by two sources: PMA-207, the Navy Program Manager for Transport Aircraft, and Conklin and de Decker, a commercial provider of aircraft performance and cost data.

Table 2.1. Performance Specifications (Future Fleet)

	C-35	C-37	C-20	C-40	C-130	2 X C-40
Max Pax	7	19	26	121	78	242
Max Payload (Lbs)	2250	6500	6500	41340	41000	82680
Seat Weight (Lbs)	15	30	30	49	5	49
Max Range (NM)	1800	6500	4220	3829	3600	3829
Avg. Speed (NM/Hr)	405	427	436	391	250	391

These performance specifications are used to determine each aircraft's capability to carry each lift requested. "2 X C-40" is used as a choice of aircraft type to handle very large lifts. This option captures the reality of Navy logistics operations, which must often move personnel and equipment for entire carrier airwings. If choosing two C-40s for one lift was not an option, an unrealistic number of lifts would be assigned a "no match" designation. The same philosophy is applied to the use of "2 X C-9" for analyzing the current fleet.

3. The Assignment Process

The first task of the assignment process is to determine which aircraft types can carry each lift. This task is accomplished mainly by comparing the lift input variables to the specifications matrix. The three steps to determining capability are 1) determining if the flight is over-water; 2) determining distance feasibility; and 3) verifying passenger, cargo, and payload capability.

For the first step, the origin and destination are used to determine whether a lift is designated as over-water. Each of the ICAO codes used in the sample data is assigned to one of nine global regions. These regions form the axes of a nine-by-nine matrix for determining whether a flight from one region to another is over-water. Flight between two regions is considered over-water if a fuel stop is not available every 640 nautical miles (NM). 640 NM is the range of a fully loaded C-12 and represents the shortest range of any of the aircraft in the study.

In the second step, the over-water designation (Y or N) is used to determine the distance feasibility of the lift for each aircraft type. If the lift is classified as not over-water, the distance of the lift cannot disqualify any aircraft type. This treatment is based

on the assumption that fuel is normally available within 640 NM of any airport when flying over land. When flying over water, however, the payload of the aircraft and its maximum range must be considered. For over-water lifts, which are mostly inter-continental, it is assumed that fuel will be available every 3,000 NM. For an aircraft type to be considered for an over-water lift, one of two situations must exist: 1) the aircraft type is capable of flying 3000 NM with the assigned load, or 2) the distance of the lift is within the range of the aircraft to fly in one leg with the assigned load. The payload and range data in the specifications matrix are used to define a performance envelope for one-leg over-water flights as depicted in Figure 2.1. In the figure, if the lift distance and payload can be plotted in the feasible region, the lift can be assigned to a C-130. If the payload is less than 22,098 pounds, the 3000NM criterion is met and the lift can be assigned as a multi-leg lift to a C-130. The max payload for a C-130 is 41,000 pounds.

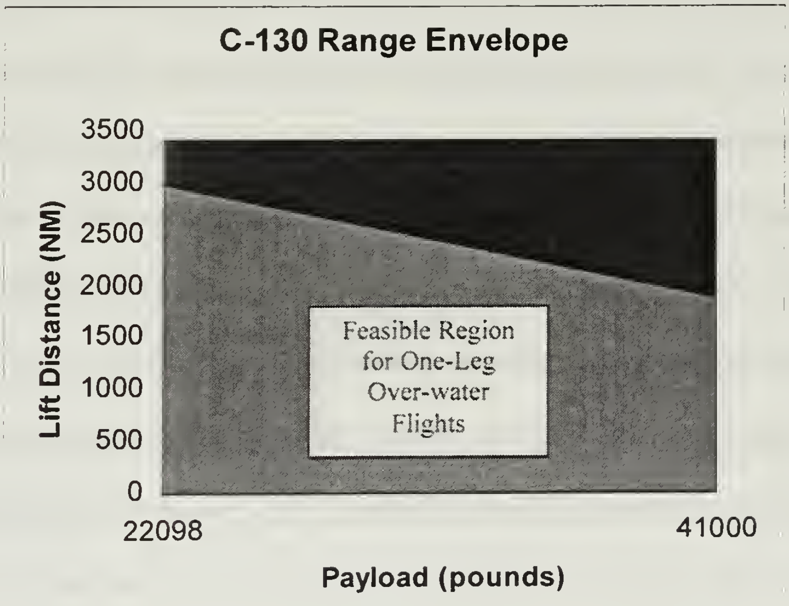

Figure 2.1. C-130 Over-water Distance Feasibility Chart

The last step in determining capability is comparing the passenger, cargo, and total payload data to the limits set in the specifications matrix. For each aircraft type, if the lift request passes the distance feasibility test and falls under the maximum limits for passengers, cargo, and payload, it is assigned a "1," indicating that the type can carry the lift. Aircraft types that cannot carry the lift are assigned a "0." The resultant binary string is then converted to a base-10 number that is designated the "lift type." Table 2.2 shows the Excel spreadsheet format through which the lift type is determined. The binary string "011111" in Table 2.2 is converted to the base-10 number "31."

Table 2.2. Sample Assignment

PAX	DISTANCE	CARGO	PAYLOAD	OW?	C-35	C-37	C-20	C-40	C-130	2 X C-40	LIFT TYPE	1° SELECT
7	2375.00	0.00	1400.00	Y	0	1	1	1	1	1	31	C-37

After determining the capability of the individual aircraft types to carry the lift, the model makes the primary aircraft selection. The lift will be assigned to the smallest capable aircraft. This assignment process promotes efficient utilization of operating funds, as hourly operating cost is proportional to aircraft capacity.[2] Therefore, assigning the lift to the smallest capable aircraft minimizes the operating cost of satisfying the lift.[3]

4. Assumptions and Limitations of the Assignment Algorithm

The exception to the operating cost rule is the relationship between the C-130 and the C-40 in the Future Mix scenario. The C-130's capacity is slightly less than the C-40, but its operating costs are significantly higher. This situation would normally lead the model to exclude assigning any lifts to a C-130 that could be assigned to a C-40.

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[2] Conklin and deDecker. *The Aircraft Cost Evaluator for Windows*. Orleans, MA: 1999.
[3] Technically, there could arise a situation where a larger aircraft's greater speed could offset its higher operating cost per flight hour; however, these situations are rare.

However, given the unique features of the C-130, notably its loading ramp and large-dimension cargo capability, it is not reasonable to exclude it from the assignment process. The assignment algorithm therefore forces the C-130 to be assigned in certain circumstances. For all lifts that could be carried only by a C-130 or a C-40, a C-40 will be chosen only if the passenger load is greater than 20. This skews the assignment toward the C-40 for passenger-intensive lifts, and toward the C-130 for cargo-intensive lifts. This treatment is consistent with current NALO scheduling practice, which assigns C-130s to cargo-intensive lifts.[4]

This model assumes that the arrival rate of lift requests is random and that requestors have sufficient flexibility in the travel window to allow repositioning of aircraft to the departure location and resolution of scheduling conflicts. In reality, NALO data show that approximately five percent of lift requests are regretted due to aircraft non-availability (all assets being utilized).

"Priority Code" is a characteristic of NALO lift requests that is not considered in this model. The model assumes that all lift requests are valid and should be fulfilled if possible. The fact that some lifts may get "bumped" for higher priority lifts is not relevant since the overall set of lift requests made and fulfilled is not significantly altered by the "bumping." Priority Code is not considered when making the primary aircraft type assignment; decisions concerning the appropriate type of passengers or cargo to be carried on a particular aircraft type are beyond the scope of this study.

[4] Interview with ADC (AW/NAC) John Chaille, Navy Air Logistics Office (NALO) Operations Chief Petty Officer, 20 September 2000.

C. PREDICTING THE IDEAL FLEET MIX

After the primary assignment has been completed for each lift request, the model calculates how many aircraft of each type are needed to meet the total demand. The result of these calculations is the "ideal fleet mix." The term "ideal fleet mix" indicates that the fleet will be capable of fulfilling the entire set of lift requests and will assign one aircraft, of the smallest capable type, to each lift request. This rule is modified by the inclusion of "2 X C-40" as an aircraft type; for each lift assigned to a "2 X C-40" aircraft, two aircraft missions will be required. The treatment of C-9s in the current fleet is identical.

1. Inputs to the Ideal Fleet Mix Model

The Ideal Fleet Mix Model uses two inputs that were present in the assignment model – lift distance and primary assignment. The primary assignment ensures that the flight hour requirement is assigned to the proper aircraft type; the distance will be used in conjunction with aircraft average speed to determine flight hours required.

2. Constraints in the Ideal Fleet Mix Model

Each aircraft type is constrained by the number of flight hours it may accumulate in one month. Data for normal and expected monthly flight hours were derived from NALO, the aircraft type Program Managers, and from Conklin and de Decker.

A significant factor in determining aircraft flight hour requirements is predicting the amount of "dead-head" time accumulated during operations. Dead-head time is that time spent in transit (empty) to pick up a lift or returning home (empty) from delivering a lift. Consider a San Diego-based aircraft that must fly to San Francisco to pick up a lift, deliver the lift to Denver and then return home to San Diego. The time spent on the legs

from San Diego to San Francisco and Denver to San Diego would be considered dead-head time if no lifts were carried on those legs. In reality, lifts are often carried on dead-head legs, and space-available (Space-A) cargo and passengers are also carried.

This model captures the lifts that are carried on otherwise dead-head legs (those lifts are assigned just like all the rest), but does not capture Space-A loads. There is comprehensive Space-A load data available, but the data do not identify how much of that load is carried on otherwise empty aircraft. NALO scheduling personnel regard the amount of Space-A load carried in CONUS as insignificant.[5] Sample estimates used for dead-head time for each aircraft type are summarized in Table 2.3. These estimates will be addressed in more detail in Chapter V.

The dead-head percentages are converted to a utilization factor (ρ) by subtracting them from one. The utilization factor is multiplied by the number of flight hours available each month to determine the number of hours available for carrying lifts. The percentage of dead-head time shown in Table 2.3 is based on estimates for the current fleet that have been assumed to be similar for the future fleet.[6]

Table 2.3. Dead-Head Flight Time (Future Fleet)

AIRCRAFT TYPE	C-35	C-37	C-20	C-40	C-130
% Dead-Head Time	15	20	20	25	45
ρ	.85	.80	.80	.75	.55

While dead-heads consume flight hours, combining lifts saves flight hours. Sample estimates of flight hours saved through combining lifts are listed in Table 2.4 for the future fleet. These percentages are applied as a flight hour discount factor (α_{FH}), thus

[5] Interview with AT1 (AW/NAC) Kenneth Eichenauer, NALO Schedules Petty Officer, 24 October 2000.

reducing the number of flight hours required for each aircraft type to complete its assigned missions.[7] The estimates appearing in Table 2.4 are also based on estimates originally made for the current fleet.

Table 2.4. Flight Hour Discount Factor (Future Fleet)

AIRCRAFT TYPE	C-35	C-37	C-20	C-40	C-130
α_{FH}	0%	0%	0%	35%	40%

3. The Ideal Fleet Mix Determination Process

The process of determining the ideal fleet mix is comprised of three basic steps: 1) converting missions assigned to flight hours required for each aircraft type; 2) converting flight hours required to number of aircraft required for each type; and 3) liquidating the "no match" cases. Appendix A is an example of the spreadsheet output of the model that produces the fleet mix and enables the comparison of different fleet mixes.

The calculation of flight hours required is a relatively simple process of summing the distances (D_n) of all lifts (L) assigned to an aircraft type, and dividing that sum by the average speed of the aircraft (S), found in the performance specifications matrix. The flight hour discount factor is applied to yield the estimated flight hours required (FH_{req}) to perform the assigned lifts. Equation 2.2 summarizes the calculation.

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[6] Ibid.
[7] Ibid.

$$FH_{req} = \frac{\sum_{n=1}^{L} D_n}{S} \times (1 - \alpha_{FH})$$

Equation 2.2. Flight Hours Required

Converting the flight hours required to aircraft required (AC_{req}) is accomplished by dividing the flight hours required by the flight hours available per aircraft. This calculation is based on a monthly average flight time available (FH), so the flight hours required must be divided by the number of months in the sample (M). Applying the utilization factor (ρ) reduces the hours per month available for each aircraft. The calculation is summarized in Equation 2.3.

$$AC_{req} = \frac{FH_{req}}{M \times FH \times \rho}$$

Equation 2.3. Aircraft Required

Since C-9s (in the current fleet) and C-40s (in the future fleet) may be assigned in pairs, the contribution of the lift assigned to the pairs requires special handling. Each of the lifts assigned to a pair of aircraft is converted to the equivalent requirement of one aircraft prior to being added to the total hours required for the type. For example, each "2 X C-40" lift is one lift, but two missions. Consequently, double the flight time of a "C-40" lift is added to C-40 flight hours required.

The lifts that were beyond the capabilities of all aircraft types were assigned a "no match" designation by the assignment algorithm. The majority of the "no match" lifts represent requests to carry a large number (>250) of passengers. These lift requirements

are liquidated by the fleet mix model by assigning them to C-40s and raising the number of C-40s by the appropriate amount. The C-40 is chosen to liquidate the "no match" lifts because of the its large passenger capacity. This feature of the model assumes that the lifts can be split into "C-40-sized" pieces.

D. ASSESSING THE CAPABILITIES OF A CHOSEN FLEET MIX

The Fleet Mix Model allows the user to specify a number of aircraft of each type for a hypothetical or current mix. The model takes the difference between the ideal mix and the specified mix and calculates the difference in load capacity for each parameter (passengers, cargo and payload) between the two. If the specified mix has *fewer* aircraft than the ideal mix, the model calculates the amount short for each parameter by deducting a percentage of capability equal to the percentage of aircraft short. For example, if the model suggested 10 C-20s to carry the assigned lifts, and the user specified a fleet that included 8 C-20s, then each parameter would be "short" by 20% of the amount assigned to the C-20. If the specified mix has an *excess* of a type of aircraft, the excess capacity generated is based on the average load assigned to that type across the entire data set. Once the deficit or excess has been calculated for each type for each load parameter, the individual parameter amounts are summed across all types to generate a total deficit or excess for each parameter. The individual and total amounts are used to compare capabilities of different fleet mix options.

E. SUMMARY

This chapter introduced the process by which a fleet mix can be chosen – and its capacity evaluated – based on a given set of demand data. The process includes a simple primary assignment algorithm and a method of converting assigned lifts into aircraft

requirements. The resulting "ideal fleet mix" can be compared to user-specified mixes to determine differences in capacity. Differences in capacity will play an important role in Chapter V, which will relate the performance of the fleet to its cost.

The next chapter will describe how the historical data set is used to generate stochastic data for estimating fleet mix requirements under uncertainty. This Monte Carlo simulation will serve to validate results of the static model and allow for a richer analysis of demand behavior and resource requirements.

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III. MONTE CARLO SIMULATION OF FLEET SELECTION

A. INTRODUCTION

The previous chapter described a static, or deterministic, model that uses a given set of demand data to generate a baseline estimate of the ideal fleet mix. The data actually used to generate fleet mixes are a compilation of NALO lift requests collected over approximately 27 months. These data give us a very good idea about what the demand was during that period, but is only an *indicator* of what is likely to occur in the future.

This study assumes the historical data to represent a reasonable approximation of the average demand in any future 27-month period. By using the historical data to represent *average* future demand, we must consider the output of the static model to represent only the *average* future fleet requirement. The static model assumes that the entire demand is known ahead of time and that lifts can be scheduled at any time during the 27-month period. Therefore, it fails to capture the variations in demand that occur as a result of random variations in lift request arrival. The static model describes a fleet that has a *mean* capability to meet all demand; therefore, it will fail to meet all demand about 50% of the time.

In order to generate a richer view of future airlift fleet requirements, the historical data must be molded into a tool for predicting future demand. Introducing uncertainty into elements of demand will allow us to simulate how variations in these elements combine to produce a broad range of outcomes.[8]

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[8] Chang, Davis L. S. and Shu S. Liao, "Measuring and Disclosing Forecast Reliability," *The Journal of Accountancy*, May 1977, pp. 80-81.

This chapter describes the methodology for introducing uncertainty into the fleet mix selection model. By converting the historical data to frequency distributions and employing Monte Carlo simulation, this stochastic model shows how demand fluctuates over time. The model allows the user to set performance targets and determine the probability of achieving those targets with a specified fleet mix.

As in the previous chapter, the discussion and examples in this chapter will focus mainly on the future fleet. A similar model is used to analyze the current fleet.

The chapter is organized in the following format:

A. Introduction

B. Applying Uncertainty

C. Constructing the Stochastic Model

D. Running the Monte Carlo Simulation

E. Summary

B. APPLYING UNCERTAINTY

It is unreasonable to believe that a precise and discrete prediction of future airlift demand can be calculated. The complexities involved with aircraft scheduling make even scheduling known demand a cumbersome process. However, if future demand follows a known pattern or trend, then average behavior can be estimated. Monte Carlo simulation is well suited to analyzing this type of situation.[9] This study utilized the Crystal Ball™ add-on program to Microsoft EXCEL® for generating a Monte Carlo simulation of fleet requirements. Allowing Crystal Ball™ to generate a random outcome for an event with a prescribed frequency distribution provides an uncertain outcome for

each time period specified in the model, but preserves the average behavior expected over time.

The model generates uncertainty in the distance for each lift assigned to each aircraft type, and in the number of lifts assigned to each type. The unique distribution of lift distances will affect the flight time required for each aircraft type. The distribution of lifts assigned to each type also will affect flight time required. The number of aircraft required is based on flight time required, so the variations in the number and distance of lifts will determine the variations in aircraft required over the selected number of simulation cycles. Appendix B shows a block diagram that describes the stochastic model process.

1. Determining the Distribution for Number of Lifts Assigned

The model assumes that the number of lifts assigned to each aircraft type, as a percentage of the total requests, will display a consistent average over time. Variation in the number of lifts assigned per period (e.g., per week) reflects the stochastic arrival rate of lift requests. The arrival rate (λ) is assumed to follow a Poisson distribution with a mean equal to the average number of arrivals as calculated from the historical data. The Poisson assumption is based on Khintchine's Theory, which states that combinations of independent and random arrival times for an event follow a Poisson distribution.[10] The event in this case is the assignment of a lift to a particular aircraft type. Since lift requests arrive in a random manner from a large number of independent requestors, the

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[9] Koller, Glenn; *Risk Assessment and Decision Making in Business and Industry*, CRC Press, 1999, p. 91.
[10] Ravindran, A., Don T. Phillips, and James J. Solberg, *Operations Research: Principles and Practice*, John Wiley and Sons, 2nd Edition, 1987, pp. 295-296.

application of Khintchine's Theory is appropriate. The Poisson random variates are generated by Crystal Ball™.

2. Determining the Distribution for Lift Distance

Crystal Ball™ allows the user to generate custom distribution assumptions when no standard distribution (normal, Poisson, Beta, etc.) fits the data. The historical data for lift distance require custom distributions. The distributions were constructed by grouping the distance data for each aircraft. For example, the distances for all C-35 flights were extracted from the total data set and copied to a separate spreadsheet page. This data was then converted into a frequency table as shown in Table 3.1.

Table 3.1. C-35 Distance Frequency Table

Bin Boundaries (NM)		
Lower	Upper	Count
0	200	1382
200	400	2235
400	600	3062
600	800	1162
800	1000	1143
1000	1200	497
1200	1400	300
1400	1600	115
1600	1800	83
1800	2000	219
2000	2200	431
2200	5000	90

Crystal Ball™ automatically converts the frequency table information into a frequency distribution function as shown in Figure 3.1. This function will be used to generate random distances for lifts.

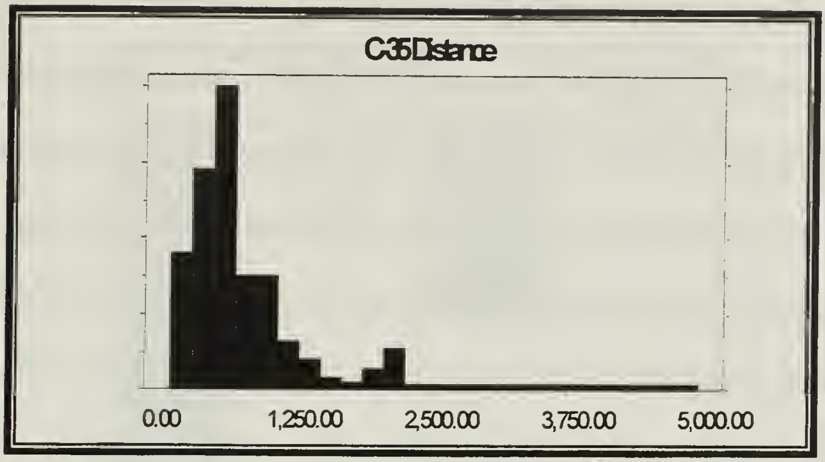

Figure 3.1. Custom Distribution for C-35 Lift Distance

3. Exclusion of Cargo and Passenger Variables

Two variables that are significant components of lift requests – cargo and passengers – are not part of the stochastic model. Excluding the cargo and passenger variables from the simulation simplifies the model and does not compromise its validity. The cargo and passenger elements in the static model provide constraints on the assignment of aircraft types. As key components of aircraft assignment, the variations in cargo and passenger amounts are captured in the Poisson distribution of aircraft assignment. Passenger and cargo amounts are not a factor in computing required flight time; therefore, variations in these elements will not be missed in generating a flight hour requirement.

C. CONSTRUCTING THE STOCHASTIC MODEL

1. Modifying the Static Model

The process of determining the required number of aircraft, described in Chapter II, changes little after incorporating the stochastic data inputs. Recall from Chapter II

that the two inputs to the ideal fleet mix model were aircraft assignment and lift distance – the same two inputs are used in the stochastic model. The number of lifts per type was an input from the assignment algorithm in the static model; in the stochastic model, this value is a product of the Poisson distribution described earlier in this chapter. Lift distance appeared in the static model as the sum of distances of all lifts assigned to each aircraft. In the stochastic model, the number of lifts generated and the distance distribution function determine the cumulative distance for each type. All other operations in the stochastic model are virtually identical to the static model.

2. Choosing the Appropriate Time Period

The stochastic model uses a one-week scheduling period. From an operational point of view, this is a reasonable window for scheduling the airlift assets. Additionally, the fleet mix model assumes that scheduling data are known in advance for the period covered, and that lifts have the flexibility to be scheduled at any time during the period. A one-week scheduling period supports these assumptions. NALO reports that approximately 95% of lift requests are received with at least one week of lead-time and that scheduling inflexibility causes a regret in about 0.3% of all lift requests. These percentages support the choice of a one-week simulation window.

3. Generating Lifts

Table 3.2 shows a portion of the lift generation page. This page contains the functions that generate the random distances based on the distribution data.

Table 3.2. Sample Lift Generation

2 X C-40	Projected Lifts	no match	Projected Lifts
1612.193	1612.193	573.4225	573.4225
1470.491	1470.491	396.2196	
1418.334	1418.334	399.142	
1587.81	1587.81	899.9204	
1676.337		844.8094	
1633.971		799.533	
1958.747			
1980.733			
1905.565			
1677.986			
1631.089			
1853.688			
1598.031			

During the simulation, Crystal Ball™ will generate random distances in each of the shaded cells. The distance value will be transferred to the adjacent cell to provide the distances for the number of lifts generated by the Poisson distribution. In the sample above, Crystal Ball™ has determined that four "2 X C-40" and one "no match" lift will be generated for this "week." As is evident in the sample, each run of the simulation can generate between zero and six "no match" lifts and zero to thirteen "2 X C-40" lifts. This is consistent with the Poisson distribution assigned to each of the types. Once the distances have been generated for the appropriate number of lifts, the "Projected Lifts" column is summed and the result is inserted into the ideal fleet mix model as "Cum. Distance." This distance is then converted to flight hours and to aircraft required as described in Chapter II. Appendix C displays the spreadsheet results of the fleet mix calculations.

D. RUNNING THE MONTE CARLO SIMULATION

1. Selecting the Forecast Cells

The Monte Carlo Simulation generated by Crystal Ball™ provides the user with the probability that a chosen parameter will achieve a specified value. In this model, the user can determine, for example, the probability that the specified fleet will have 150% capacity, or the probability that six or fewer C-20s will be required to satisfy all C-20 demand. Crystal Ball™ allows the user to select almost any parameter to be forecasted. The parameters of interest for this study are the number of each aircraft type required and the excess or deficit of capacity resulting from a fleet mix choice. The excess or deficit can be stated in percentage of load assigned, in pounds, or in passengers.

2. Selecting the Number of Trials

The user must tell Crystal Ball™ how many times it should run the simulation. Each "trial" is a one-week estimation of demand and aircraft requirement. The total number of trials should be sufficient to generate a forecast distribution that has a low mean standard error. For this model, running 2,000 trials consistently produced mean standard errors that were less than 1% of the mean value. Running additional trials won't compromise the results, but may not be worth the incremental computation time.[11]

3. Interpreting the Output

Figures 3.2 and 3.3 show two examples of forecast output from the simulation. Figure 3.2 is the distribution of C-130s required to satisfy all of the C-130 assigned lifts. The horizontal axis indicates number of aircraft; the vertical axis indicates the probability that a chosen number of aircraft will be required. In this example, nine or fewer C-130s

were required in 88.35% of the trial runs. 88.35% represents the cumulative probability of needing one to nine C-130s. This translates to an 88.35% certainty that a fleet containing nine C-130s would satisfy all weekly demand. This forecast does not indicate how much excess capacity is associated with the C-130 fleet, nor does it measure the unsatisfied demand in the remaining 12% of the weeks.

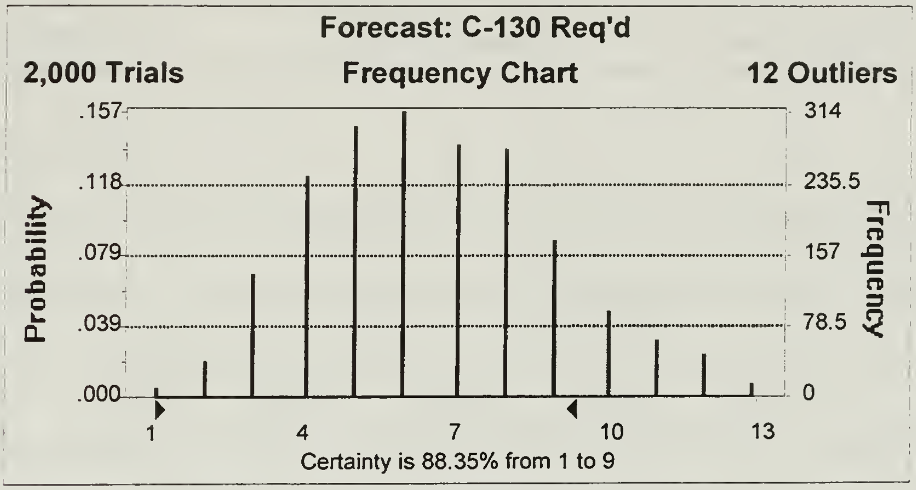

Figure 3.2. Forecast of C-130 Aircraft Required

Figure 3.3 shows the distribution of the capacity of the C-20s during the simulation run. In this figure, the horizontal axis represents the load carrying capacity of the C-20 fleet, given in percent of load assigned. The figure indicates that in 34.9% of the trials, the C-20s in the fleet had excess capacity – that they could carry 100% or more of the assigned load.

The model will generate a total fleet capacity figure, but the limitations of this value must be considered. The total fleet capacity figure assumes that all load deficits can be carried equally well by the aircraft types that have excess capacity. While some

[11] Koller, pp. 94-95

combining and splitting of flights can occur to get loads on bigger or smaller planes, it is not realistic to assume that all deficits can be liquidated in this manner. It is especially unlikely that large cargo loads, perhaps assigned to C-40s, would be split up and carried on C-35s if there were excess capacity in the C-35 fleet.

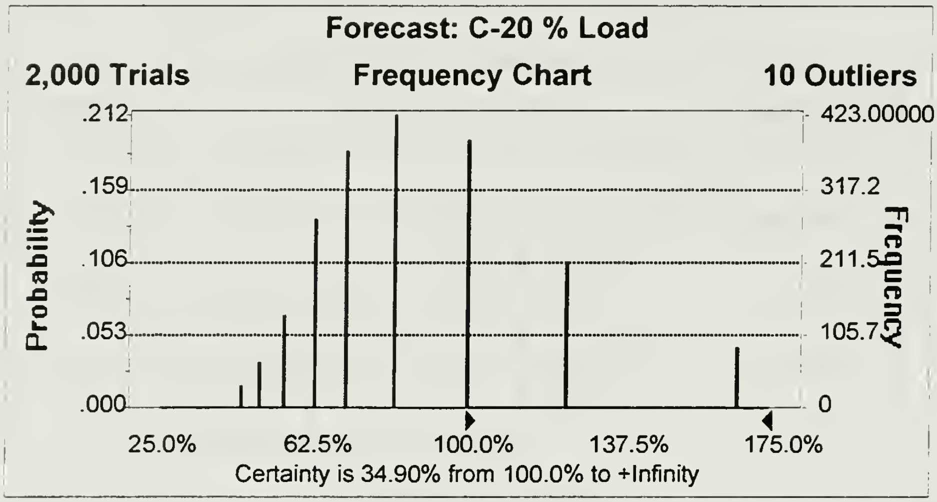

Figure 3.3. Forecast of C-20 Load Capability

E. SUMMARY

The stochastic model for determining the ideal fleet mix has made the model richer. The model now produces results that mimic the characteristics of the historical data without assuming uniform behavior. Introducing uncertainty into the model increases realism and provides the decision makers with a spectrum of possible outcomes. The model is also a smaller and more responsive program than the static model, which analyzed nearly 24,000 lines of data. The decisions resulting from this model will become inputs to the Life Cycle Cost model, which is the topic of Chapter IV.

IV. LOGISTICS AIRFLEET LIFE CYCLE COST (LCC) MODEL

A. INTRODUCTION

This chapter describes the model used to compute the Life Cycle Cost (LCC) of a fleet mix chosen by the user. The LCC model will be used to examine the financial aspects of the fleet choices made using the previously described fleet mix models. Application of the LCC model will provide the final element of the Cost Benefit Analysis described in Chapter V.

The LCC model uses a combination of commercially provided cost data and data from Navy sources. Commercial data are used for the aircraft that are new to the Navy inventory, as there are no historical data on which to rely. Commercial data are also used where the research sponsor did not provide Navy data. A software package from Conklin and deDecker Company (C&D) was used to estimate the commercial cost data required for the study. The data from C&D are based on commercial operations of aircraft that are analogous to the Navy models. The C&D software allows adjustment of operational factors to capture Navy-relevant costs. This study does not claim that the Navy will see costs equal to the commercial estimates, but until valid historical data are available, the C&D data provide a reasonable starting point for analysis.

The following features of the LCC model increase its utility: 1) capture of creeping Operations & Maintenance (O&M) costs; 2) capture of Service Life Extension Program (SLEP) costs; 3) infinite horizon cost concept; and 4) modifiable acquisition and retirement schedules. These features are described in the following sections, as is the basic LCC calculation. The format of the chapter is:

A. Introduction

B. The Basic LCC Model

C. Improvements to the Model

D. Output of the Model

E. Summary

B. THE BASIC LCC MODEL

The model generates a life cycle cost based on aircraft life span, hourly operating cost, and acquisition cost. The cost elements used are depicted in Table 4.1. These data are easily modified to incorporate updates. The life spans used are 20 years for the C-12, C-35 and C-20, and 30 years for C-9, C-40 and C-130. The life spans are also easy to modify.

Table 4.1. Aircraft LCC Elements

Costs in FY00$	C-12	C-35	C-20	C-37	C-9	C-40	C-130
APN ($M)	$3.35	$6.65	$26.00	$39.50	$22.60	$44.00	$40.00
Annual O&M Cost ($M)	$0.48	$0.61	$1.26	$0.99	$2.02	$2.85	$1.19
Total DC/FH ($)	$660	$850	$1,396	$1,096	$1,346	$1,902	$1,526
Monthly FH	60	60	75	75	125	125	60
Ann. FH	720	720	900	900	1500	1500	720

The LCC model is constructed in a Microsoft EXCEL® workbook. The one-cycle LCC is the cost to purchase, operate and retire one aircraft over its normal life span. The calculation of one-cycle LCC is a relatively simple present value calculation

(continuous compounding assumed) and is shown in Equation 2.1.[12] The variables in the equation are *net present value of life cycle cost* (NPV of LCC); *acquisition cost* (A); *annual operations and maintenance cost* (O); *discount rate* (α); and *aircraft useful life* (L). In equation 4.1, and for the entire LCC model, retirement and disposal costs are assumed to be negligible.

$$NPVofLCC = A + O\left(\frac{1-e^{-\alpha L}}{\alpha}\right)$$

Equation 4.1. One-Cycle LCC

The discount rate used for the study is 4.2%. This is the *Real Discount Rate* specified by the Office of Management and Budget (OMB) in OMB Circular A-94. This rate is to be used for discounting constant year dollar flows for long-term government programs.[13] All costs discussed in this study will be in constant fiscal year (FY) 2000 dollars unless otherwise noted.

C. IMPROVEMENTS TO THE MODEL

The basic LCC model described above gives the user a good baseline estimate of the total LCC. This study suggests four enhancements to the basic model that will provide a richer estimate of LCC. The improvements are:

1. Creeping O&M Costs
2. Service Life Extension Program (SLEP) Cost
3. Infinite Horizon and Equivalent Annual Net Cost (EANC)

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[12] Gates, William R., Young Kwon, Timothy Anderson, Alan Washburn, Mitch McCarthy, and Robert Stevenson; *Marine KC-130 Requirements Study*, Naval Postgraduate School, Monterey, CA, October 1999, pp. 16-17.

[13] Office of Management and Budget; *Guidelines and Discount Rates for Benefit-Cost Analysis of Federal Programs*; United States Government, 29 October 1992 (Revised January 2000), Appendix C.

4. Acquisition and Retirement Scheduling

1. Creeping O&M Costs

It is a common aviation phenomenon that aircraft operating and maintenance costs "creep" up as aircraft age.[14] O&M cost creep is typically modeled as a constant percentage increase in annual O&M cost; this increase, or creep rate, commences after an initial "creep free" period. The portion of O&M cost subject to creeping varies from type to type. The creep rate (β) is applied to that portion of O&M cost that is expected to creep (O_C) after the creep free period (F) for the rest of the aircraft's life (L). The present value of the creep in O&M cost over the life of an aircraft is calculated in Equation 4.2 using the discount rate (α) described in the previous section.[15]

$$PV_{creep} = O_C\left[\frac{1-e^{-\alpha F}}{\alpha} + \frac{e^{-\alpha F} - e^{-\beta F-(\alpha-\beta)L}}{(\alpha-\beta)}\right]$$

Equation 4.2. Present Value of Creeping O&M Costs

A comprehensive study to determine O&M cost creep factors for the current or existing fleet is beyond the scope of this study. However, the model is set up to capture cost creep should the user have reliable estimates of creep factors. The present value of non-creeping, or static, O&M costs is calculated in Equation 4.3. O_S represents the portion of O&M costs that does not creep.

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[14] Kusek, L., *KC-130F Replacement Study*, Center for Naval Analyses, CRM 93-238.09, 1994.
[15] Gates, *et al.*, p. 16.

$$PV_{static} = O_S\left(\frac{1-e^{-\alpha L}}{\alpha}\right)$$

Equation 4.3. Present Value of Static O&M Cost

2. Service Life Extension Program (SLEP) Cost

It is common for military aircraft to undergo Service Life Extension Programs (SLEPs) to increase the useful life of the aircraft. These programs often include extensive modifications to avionics and engines to capture the benefits of improved technology. Engineering studies and evaluations of the airframe, as well as structural modifications, may be conducted to extend component life.

Incorporating the impact of a SLEP on the LCC is relatively straightforward, assuming that reliable data exist as to the cost and timing of the SLEP, as well as the life extension generated by the SLEP. Equation 4.4 shows the calculation for the present value of conducting a SLEP (PV_S) at year Y_S for cost C_S. The model does not capture changes to cost creep factors that may result from a SLEP.

$$PV_S = C_S \times e^{-\alpha Y_S}$$

Equation 4.4. Present Value of SLEP Cost

The two enhancements already discussed, O&M creep and SLEP consideration, produce additional present values that can be added to the basic LCC figure. The remaining enhancements are manipulations of the current data to provide different points of view from which to analyze LCC.

3. Infinite Horizon and Equivalent Annual Net Cost (EANC)

This study assumes that the demand for airlift over the past 27 months represents a realistic estimate of future demand. If we extend this assumption indefinitely, we are presuming that demand won't change significantly in the foreseeable future. This assumption allows the decision maker to take a long-range look at the fleet LCC. By using an infinite time horizon, we can compute the cost of not only purchasing a particular fleet of aircraft one time, but also of operating that fleet indefinitely by retiring and replacing aircraft as they reach the ends of their useful lives. While new types will no doubt appear in the future, if one considers the upgrades to be evolutionary in nature then the infinite horizon concept remains valid.[16]

The method of computing the present value of operating an aircraft over an infinite horizon (PV_∞) involves adding the present values of the acquisition cost, the SLEP cost and the creeping and static O&M costs and converting the sum to an infinite horizon by dividing by $1 - e^{-\alpha L}$, where L is the useful life of the aircraft after SLEP. If there is no SLEP planned, $PV_S = 0$ and L = aircraft life. The long form of the calculation is shown in Equation 4.5.

$$PV_\infty = \frac{A + PV_S + PV_{static} + PV_{creep}}{1 - e^{-\alpha L}}$$

Equation 4.5. Present Value of Infinite Operation

Equation 4.5 produces a useful result, but the magnitude of the number, usually in the two to four *billion* dollar range, makes it a hard number to interpret. A more

comprehensible value to use for comparison is the Equivalent Annual Net Cost (EANC). The EANC is an amount that, if paid annually for the life of the project (an infinite horizon in this case), would have the same NPV as the project. The equation for converting NPV to EANC is presented as Equation 4.6.[17] For projects using an infinite time horizon, $n = \infty$; therefore, the denominator becomes one and EANC becomes NPV times the discount rate.

$$EANC = \frac{NPV \times \alpha}{1-(1+\alpha)^{-n}}$$

Equation 4.6. Equivalent Annual Net Cost (EANC)

Converting the NPV to an EANC provides a result that has a magnitude on the order of 100 million dollars per year; this is more user-friendly than a two – four billion dollar number that applies to an infinite amount of time.

4. Acquisition and Retirement Schedules

The basic LCC model, with the three enhancements described thus far, makes it easy to calculate a LCC figure for an entire fleet by summing the present value amounts for each aircraft type. This result, however, is accurate only if the entire fleet is purchased at one time. . . hardly a realistic scenario. The LCC picture can be made more realistic by allowing the user to specify the year in which each aircraft is purchased. Additionally, since the C-12s, C-20s, C-9s, and C-130 in the current fleet will be retired during the time frame of this study, it is appropriate to carry the O&M costs for these aircraft until they leave the fleet.

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[16] Ibid, p. 6.

[17] Boardman, Anthony E., David H. Greenberg, Aida R. Vining, and David L. Weimer; *Cost-Benefit Analysis: Concepts and Practice*, Prentice Hall, 1996, pp. 139 – 140.

The enhanced LCC model allows the user to input both procurement and retirement schedules for the appropriate aircraft. This option allows decision makers to compare various acquisition schedules and balance the financial effects of delaying acquisition against the operational and financial considerations of maintaining older aircraft.

The procurement schedule portion of the enhancement takes both the one-cycle LCCs and infinite horizon LCCs and discounts them by the number of years that procurement is to be delayed. This has the predictable effect of making procurement of an aircraft cheaper if it is purchased later. The LCCs for all aircraft of a type are summed after they have been discounted. The sum captures the total present value, in FY 2000 dollars, of the LCCs (one-cycle and infinite horizon) for each type. The NPV of the infinite horizon LCC is then converted to EANC as previously discussed.

For aircraft currently in the fleet (C-12, C-20, C-9 and C-130), the retirement schedule enhancement allows the user to input the number of aircraft to be retired in each year of the program. The model calculates the total O&M costs for the old aircraft remaining on duty, discounts these costs, and reports the NPV of O&M costs in FY 2000 dollars for each type. Both recurring O&M costs and intermittent O&M costs (airframe modifications, for example) are captured by this enhancement. The NPV of the O&M total is added to the one-cycle LCC figure.

It is not appropriate to add the O&M costs to the EANC because the O&M costs do not represent infinitely repeated expenditures; the O&M costs for retiring aircraft will cease when those aircraft leave the fleet. If the costs were added to the EANC, it would

erroneously inflate the EANC figure. Therefore, EANC and O&M must be considered separately when comparing fleet options.

Appendix D displays the LCC information for the C-130. Items of particular interest in this worksheet are the "# Retired" and "# New Purchased" columns, which allow the user to specify the retirement and procurement schedules; and the "Other O&M" column, in which the user can specify amounts for non-recurring expenses. The LCC model contains a sheet similar to Appendix D for each aircraft type in the fleet (current and future).

Appendix E displays the results of the LCC calculations. The two tables show LCC information by aircraft type and for both the basic (buy all at once) model and the enhanced (adjustable procurement schedule) model.

D. SUMMARY

The LCC model allows the user to apply a cost to the fleet mix options developed with the ideal fleet mix model. The model uses both government and commercial data to calculate a base LCC estimate for each aircraft type. The estimate is refined by applying tools that capture the effects of cost creep, SLEPs, and procurement and retirement schedules. The model also incorporates an infinite horizon calculation that produces an equivalent annual net cost (EANC); the EANC provides for an "apples to apples" comparison between fleet mix options. In Chapter V, the ideal fleet mix model and LCC model will be used to examine the tradeoffs associated with different fleet options.

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V. PERFORMANCE AND COST OF FUTURE FLEET MIX OPTIONS

A. INTRODUCTION

The Fleet Mix Model provides the opportunity to assess, in comparable terms, the capabilities of the current fleet and future fleet options. The Life Cycle Cost (LCC) model calculates the costs of the future fleet options. The costs and capabilities of future fleet options are assessed in this chapter in a two-stage analysis.

In the first stage, the performance of the current fleet is calculated and used as a starting point for designing future fleet options. The stochastic Fleet Mix Model generates fleet mix options that demonstrate desired performance parameters. Four future fleet options are developed, each having a unique set of performance characteristics.

The second stage of the analysis plugs the four fleet mix options into the Life Cycle Cost Model. The results of the LCC analysis provide insight into the costs of differing priorities. The Equivalent Annual Net Cost (EANC) and Net Present Value of Operating and Maintenance Costs (NPV of O&M) introduced in Chapter IV are the financial measures used to compare options.

After the two-stage analysis, enhancements to the LCC Model are considered. By applying acquisition and retirement schedules, the model illustrates the fiscal effects of timing in changing from the current fleet to the future fleet.

The chapter is organized in the following format:

A. Introduction

B. Stage I: Developing Fleet Options

C. Stage II: Calculation of Costs of Fleet Mix Options

D. LCC Enhancements

E. Summary

B. STAGE I: DEVELOPING FLEET OPTIONS

1. Assessing the Performance of the Current Fleet

The first step toward determining the options for the future airlift fleet is determining the capability of the current fleet. The level of performance demonstrated by the current fleet is used as a guide for determining the future fleet options. There are four parameters used to assess the capabilities of a fleet:

1) *average weekly capacity*, μ – the percentage of assigned load that the entire fleet can carry in an average week;

2) *probability of meeting all demand*, $P(C \geq 100)$ – the probability that the fleet can carry all assigned load (C = fleet capacity; units of C are "percent of assigned load");

3) *probability of having 50% excess capacity*, $P(C \geq 150)$ – the probability that the fleet has the capacity to carry at least 50% more load than is assigned;

4) *probability of having 100% excess capacity*, $P(C \geq 200)$ – the probability that the fleet has the capacity to carry at least twice the assigned load.

The performance parameters are calculated for the entire fleet as well as for each aircraft type. For the aircraft types, μ and C refer to the load assigned to each aircraft type. In much of this chapter, only fleet information is provided. A comprehensive report, including all aircraft type data generated, is presented as Appendix F.

It is important to count the proper number of aircraft in determining the "current fleet." The goal of the counting process is to determine the number of each aircraft type that is normally available for JOSAC or NALO scheduling in a given week. The number is defined to exclude aircraft scheduled by other entities, aircraft in depot level maintenance, aircraft deployed overseas and aircraft dedicated to training missions only. A sample of the derivation is provided in Table 5.1.[18] The combined current fleet mix is presented as Table 5.2.

Table 5.1. Determination of Current Fleet of C-9s

Total Owned	- Scheduled by USMC	- Average # in Depot Maint.	- Reserved for Training	- Deployed out of CONUS	= Available for Scheduling
29	- 2	- 10	- 2	- 3	12

Table 5.2. Current Fleet Mix

C-12	**C-20**	**C-9**	**C-130**	**Total**
27	3	12	14	56

The aircraft quantities from Table 5.2 are entered into the stochastic fleet mix model for the current fleet as "Aircraft Available." The Monte Carlo simulation is then run to determine the performance of the current fleet against the randomly generated demand. The performance parameters for the current fleet are shown in Table 5.3.

Table 5.3. Performance of the Current Fleet

Fleet Mix	# of Aircraft	μ	$P(C \geq 100)$	$P(C \geq 150)$	$P(C \geq 200)$
Current	56	161%	.91	.59	.17

[18] AT1 Eichenauer, 24 October 2000.

The results displayed in Table 5.3 indicate that the current fleet has an average capacity of 161% of assigned load; this means that 50% of the time (sampled in weeks), the fleet will have 61% or more excess capacity. The probability that the fleet will be able to carry all demand in any given week is 0.91.

2. Option A: One-For-One Aircraft Swap

An easy option for fleet replacement is to simply replace each aircraft with one of the new models. In this option, we replace each C-12 with a C-35 and each C-9 with a C-40. The C-20 and C-130 have no replacement at this time, so their numbers remain constant. The C-37 is not a direct replacement for any aircraft, so it is left out. The fleet mix for Option A is shown in Table 5.4.

Table 5.4. Option A: One-For-One Replacement

C-35	C-37	C-20	C-40	C-130	Total
27	0	3	12	14	56

The inventory from Table 2.4 is entered into the stochastic fleet mix model for the future fleet as "Aircraft Available." Table 5.5 shows the results of the Monte Carlo simulation. Replacing the C-12s and C-9s with newer, higher performing models significantly increases all four parameters of interest.

Table 5.5. Performance of Fleet Option A

Fleet Mix	# of Aircraft	μ	$P(C \geq 100)$	$P(C \geq 150)$	$P(C \geq 200)$
Option A	56	185%	1.0	.86	.29

The contribution of the C-35 is its increased speed, which allows it to complete more lifts in fewer hours. The C-35 is assigned a similar number of lifts as the C-12, but has nearly twice the speed; therefore, the C-35 provides nearly twice the small-lift capacity of the C-12.

The contribution of the C-40 is a greatly increased capacity and longer range. The C-40 and C-9 have roughly the same speed, but the C-40's increased cargo and passenger capabilities and its longer range combine to provide about 25% more large-lift capacity than the C-9.

3. Option B: Achieving Similar Performance

If decision makers are happy with the performance of the current fleet, and wish to avoid spending funds on excess capacity, they will seek a fleet with similar performance to the current fleet. It can be presumed that the resulting fleet will contain fewer aircraft, given the performance of Option A.

Before determining the appropriate mix, "similar performance" must be defined. Ideally, all performance parameters would be identical; however, identifying the fleet that matches exactly is extremely difficult. This study focuses on μ as the main performance indicator.

The method of determining a fleet with similar performance is trial-and-error. Once a fleet with a similar μ was identified, small changes were made to attempt to bring the other parameters into agreement. Experimentation with small changes in aircraft numbers for each type resulted in the fleet depicted in Table 5.6; the performance of this fleet is shown in Table 5.7.

Table 5.6. Option B: Similar Performance

C-35	C-37	C-20	C-40	C-130	Total
15	0	3	11	14	43

Table 5.7. Performance of Fleet Option B

Fleet Mix	# of Aircraft	μ	P(C≥100)	P(C≥150)	P(C≥200)
Option B	43	167%	1.0	.70	.15

It is not surprising that similar performance was acquired by reducing the number of C-35s and C-40s – the aircraft types that generated the increased performance of Option A. As the fleet that best represents *status quo* capability, Option B will be used as the benchmark for comparing the performance of other future fleet options.

4. Option C: Focus on Increased Capacity

One possible priority for the Navy airlift fleet designer is total fleet capacity. This number represents the amount of capacity the fleet can carry if aircraft types with extra airframes can use those airframes to carry lifts for aircraft types that have a deficit of capacity. Generally, increased capacity will come from raising the number of C-40s. It is important to remember that the total capacity concept makes the assumption that any lift can be combined and any lift can be split.

If the decision maker wishes to invest in a fleet with increased capacity over the current fleet, the best option is to purchase more C-40s. The aim in developing this fleet mix is to increase total fleet capacity without increasing the number of aircraft over the benchmark and without significantly decreasing C-35 capacity below the historical C-12

performance levels. The resulting mix is shown in Table 5.8; the performance of Option C is depicted in Table 5.9.

Table 5.8. Option C: Focus on Increased Capacity

C-35	C-37	C-20	C-40	C-130	Total
15	0	3	14	14	46

Table 5.9. Performance of Fleet Option C

Fleet Mix	# of Aircraft	μ	P(C≥100)	P(C≥150)	P(C≥200)
Option C	46	202%	1.0	.93	.50

The reduction in C-35 inventory caused a significant reduction in the C-35 capacity from the benchmark level (see Appendix F). However, C-35 capacity remains above the level of C-12 capacity in the current fleet. The addition of four C-40s provides a 35% increase in average fleet capacity over the benchmark. This fleet also demonstrates significant increases in the probability of having excess capacity.

5. Option D: Focus on Increased Flexibility

Flexibility is another concern for airlift planners. A flexible fleet provides service with less waiting and has a fleet mix that represents the characteristics of the demand set. For example, if the demand set contains a large number of small lifts and fewer large lifts, the fleet will have more C-35s and fewer C-40s. A fleet with more C-40s would have the capacity to carry the total load, but requestors would have to wait more often for lifts to be combined or for busy aircraft to become available. In a flexible fleet, the lift is more likely to be assigned to an aircraft of appropriate size than in the benchmark fleet.

The goal of the flexible fleet is to provide faster service and increase utilization of aircraft capacity.

The mix chosen for Option D is shown in Table 5.10; the performance of Option D appears in Table 5.11.

Table 5.10. Option D: Focus on Increased Flexibility Capacity

C-35	C-37	C-20	C-40	C-130	Total
17	6	7	9	14	53

Table 5.11. Performance of Fleet Option D

Fleet Mix	# of Aircraft	μ	$P(C \geq 100)$	$P(C \geq 150)$	$P(C \geq 200)$
Option D	53	162%	.99	.64	.10

Option D provides the same overall fleet capacity as the benchmark, but the capacity is spread out over all types, not concentrated in the C-40 inventory (See Appendix F). Most notably, C-20s and C-37s are carrying significantly more of their assigned lifts, rather than relying on C-40s to take up the slack.

C. STAGE II: CALCULATION OF COSTS OF FLEET MIX OPTIONS

The four fleet mix options introduced in the previous section are evaluated individually by the LCC model. The cost reported is the equivalent annual net cost (EANC) of the fleet. This application of the model assumes that the entire fleet will be purchased in FY 2000. The model also assumes that the current fleet is replaced at the same time and has insignificant residual value.

The results of the fleet mix calculations are shown below in Table 5.12.

Table 5.12. EANC of Fleet Mix Options

Option	A	B	C	D
Description	Similar Mix	Similar Performance	Increased Capacity	Increased Flexibility
# of Aircraft	56	43	46	53
EANC	$153M	$134M	$150M	$161M

Option B was designated as the benchmark for performance because it represents a similar capability to the current fleet. It is also a good choice for benchmarking cost because it is the low-cost alternative.

D. ENHANCING THE EANC ESTIMATE

Chapter IV described enhancements to the LCC Model that increase its utility and allow decision makers to produce a richer output than the simple model. The enhancements apply the effects of acquisition and retirement schedules, creeping costs and SLEPs. No data were collected to estimate creeping cost and SLEP cost elements; therefore there will be no analysis of this enhancement. This section applies procurement and retirement data and describes their impact on the EANC of the benchmark fleet mix option, Option B. The acquisition and retirement schedules were developed after conversations with the various aircraft program managers, and represent inferred rather than official data. An example of an acquisition and retirement schedule is shown in Appendix G.

Each fleet option immediately phases in C-35s and C-40s, while new C-20s and C-130s are purchased when the current aircraft reach the end of their expected lives. C-12s and C-9s are retired as the C-35s and C-40s come into service.

The recalculated EANC for Option B appears in Table 5.13. The table also lists the NPV of the O&M costs for the aircraft that will be retired. Due to the varying time periods involved for each aircraft type, and the fact that these costs will not be renewed, it is not appropriate to convert the O&M cost to an annual equivalent.[19] This NPV of O&M will be spent over approximately ten years (until all the old C-130s are retired), but will not be spent equally in each year and will not be renewed with the new purchases.

Table 5.13. Option B Enhanced Cost Estimate

Type	# Purch.	NPV of Old Aircraft O&M	EANC of New Aircraft
C-12	0	$34M	
C-35	15		$15M
C-37	0		
C-20	3	$18M	$8M
C-9	0	$65M	
C-40	11		$54M
C-130	14	$146M	$31M
Total:	**43**	**$263M**	**$108M**

The resulting EANC, $108M, is significantly less than the basic LCC result of $134M. $108M is a more useful value because it captures the effects of the time value of money. The delay in purchasing aircraft produces a much lower EANC than the "all at once" method. The penalty for the delay however, is the O&M costs of operating the aging aircraft during the acquisition period. While it is problematic to convert the O&M costs to an annual value that can be added to the EANC, the O&M NPV must still be considered as a "penalty" for delaying acquisition. EANCs and O&M costs for the other

[19] Boardman, Anthony E., David H. Greenberg, Aida R. Vining, and David L. Weimer, *Cost-Benefit Analysis: Concepts and Practice*, Prentice Hall, 1996, p. 140.

fleet mix options are calculated using similar retirement and acquisition assumptions; the resultant amounts appear in Table 5.14.

Table 5.14. Costs for Fleet Mix Options (Enhanced)

Option	A	B	C	D
Description	Similar Mix	Similar Performance	Increased Capacity	Increased Flexibility
# of Aircraft	56	43	46	53
NPV of Old Aircraft O&M	$302M	$263M	$283M	$263M
EANC of New Aircraft	$123M	$108M	$121M	$136M

It is not surprising that the two options with the highest NPV of O&M, Options A and C, are also the options with the larger numbers of C-40s. The larger number of C-40s requires a longer acquisition time period, thus extending costly C-9 operations.

E. SUMMARY

1. Evaluating the Options

The fleet mix and life cycle cost models paved the way for developing four basic fleet mix options and calculating a cost for each option. The four options represent four different priorities that may be pursued by decision makers. Each option features an EANC for the new aircraft that will be acquired, as well as a penalty associated with operating old aircraft until they retire.

Option A represents a simple replacement of old aircraft with new. This fleet exhibits a marked improvement in performance over the current fleet. The increased range and cargo carrying capacity of the C-40, and the increased speed of the C-35 are the main factors in the performance boost. This fleet is a good option if the Navy wishes to maintain the current number of aircraft conducting the airlift mission and wants a

blend of capacity and flexibility. In terms of cost, it ranks second to highest in EANC and has the highest O&M.

Option B duplicates the performance of the current fleet and is the performance benchmark for the four options. Option B requires fewer aircraft than Option A and would be a good choice if the Navy's goal is to maintain performance while holding down costs. This smaller fleet has a shorter acquisition time and thus has lower O&M costs from the retiring aircraft. The EANC for option B is the least expensive of the four options.

Option C takes advantage of the C-40's large capacity to produce a fleet with increased total capacity over the benchmark. This option would provide large lift, long-range surge capacity, such as might be needed in a wartime scenario. This fleet is approximately ten percent more costly, in terms of EANC, than the benchmark fleet, but returns over 30% more average capacity. The O&M cost for Option C is second highest of the four options.

Option D is a mix that achieves a higher degree of flexibility than the benchmark. Defining "flexibility" in quantifiable terms is beyond the scope of this study, but it is not an impossible task. The qualitative idea behind "flexibility" is building a fleet that fits the lift requests rather than combining lifts to satisfy requests with large aircraft. Flexibility implies a reduction in time spent waiting for an aircraft. Timeliness of lift satisfaction can be a priority during peacetime or wartime. A fleet that displays flexibility will typically be more expensive than a fleet that contains more large capacity aircraft. In this case, Option D has the highest EANC but, due to the shorter acquisition timeline required for C-40s, has a lower O&M cost.

2. C-130 and C-37 Considerations

C-130 inventory was not modified during fleet mix option development. The fleet mix and LCC models recommend reducing the C-130 inventory in favor of the C-40. However, the models do not capture the unique characteristics of the C-130, namely its oversized cargo capability, its short-field take-off and landing capability and its loading ramp. Information from the C-130 Program Manager indicates that C-130 numbers are not likely to decline in the foreseeable future; therefore, it is appropriate to keep the number of C-130s constant for the study.[20]

The C-37 is another type that is not favored by the LCC model. While it does have longer range than the C-20, it carries fewer passengers and costs about 1.5 times as much as a C-20. The C-37s extended range is not a factor in any lifts assigned by the fleet mix model, therefore a C-20 could complete any mission assigned to a C-37. The C-37's operating cost per flight hour is less than the C-20, but not enough to offset the high acquisition cost. Information from the C-37 Program Manager indicates that the C-37 will most likely be used for VIP missions only, and will not be scheduled by NALO or JOSAC.[21] This implies that it will not fill any of the missions modeled in this study. If the C-37 is excluded from Option D, it is appropriate to increase the number of C-20s by six aircraft. The modified Option D would have an EANC of $130M and an O&M cost of $265M.

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[20] Interview with CDR Jack Reape, USNR, CNARF C-130 Program Manager, 01 November 2000.
[21] Interview with LCDR Lawrence McCabe, USN, Naval Air Systems Command C-37/C-20 Program Manager, 05 November 2000.

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VI. CONCLUSIONS REGARDING THE LOGISTICS AIRFLEET ASSESSMENT METHODOLOGY

A. INTRODUCTION

This chapter provides a brief review of the elements of the logistics airfleet assessment methodology and offers concluding statements regarding its utility. The discussion is divided into three sections that will address the fleet mix model, the Life Cycle Cost (LCC) model, and the analysis conducted using the complete assessment methodology. The chapter concludes by suggesting topics for further research.

B. THE FLEET MIX MODEL

The fleet mix model captures the most significant elements of a very complex issue, determining the proper aircraft to assign to a lift request. The model incorporates NALO's nominal scheduling priorities without attempting to capture all the nuances associated with assigning aircraft. Priorities captured in the model include 1) assigning the smallest capable aircraft; and 2) making appropriate assignment based on realistic over-water considerations.

The model also captures aircraft utilization effects by considering the impact of dead-heads and lift combination. The flight hour discount factor (α_{FH}) applies the effect of lift combinations to reduce the number of flight hours required of each aircraft type. The utilization factor (ρ), captures the fact that aircraft flight hours are wasted when an aircraft travels empty to pick up a lift or returns home empty after dropping off a lift. These variables were estimated based on limited information provided by NALO scheduling personnel. In order to increase the validity of the results, additional information should be gathered to refine the estimates of α_{FH} and ρ.

The fleet mix model does not provide for discrimination based on priority. The model assumes that all lift requests represent valid lift requirements and that no mission requires a "VIP" aircraft. This assumption was supported by the sponsor's requirement that the study provide an unbiased estimate of aircraft requirements. Should decision makers require a refined result that incorporates priority considerations, the assignment model could be modified.

The stochastic output produced by the fleet mix model is a richer product than a "one-number" fleet mix answer. Although interpreting and explaining the results of the Monte Carlo simulation are more complicated than providing a discrete answer, the probabilistic portrayal of fleet performance gives the decision maker a better idea of what is likely to transpire over a large period of time.

C. THE LIFE CYCLE COST (LCC) MODEL

The LCC model captures available cost data and transforms them to a format that allows for comparability across fleet mix options. The equivalent annual net cost (EANC) method used by the model enables the user to vary not only the mix of aircraft selected, but also the acquisition schedule for those aircraft. Inclusion of the retirement schedule further increases the realism of the model by capturing the cost of operating older aircraft. Thus, the model captures both the "time value of money" benefit of delaying aircraft acquisition and the penalty of extending the operation of older models.

The cost data used in this study come from two data sources, the Navy and a commercial company. Commercial data were required because the Navy does not yet have reliable and consistent cost data for the newer aircraft models (C-35, C-37, C-40). However, commercial data could not be used for all aircraft because the C-130 has no

commercial equivalent. Combining the two data sources is the best option until the Navy is able to provide stable data for all aircraft in the inventory.

The "two-number" cost result, which includes EANC and operating and maintenance (O&M) cost, is not as user-friendly as a simple one-number result. However, it is not appropriate to combine the two numbers. The EANC is based on the "continuous replacement" assumption that states that the aircraft involved will be replaced by comparable units at the end of their useful lives; the O&M cost only applies for the remainders of the lives of the currently operating aircraft. One benefit of the "two-number" result is that it allows the decision maker to observe separately the effects of acquisition and retirement schedules.

D. THE ASSESSMENT METHODOLOGY AS AN ANALYSIS TOOL

The airfleet assessment methodology clearly shows the operational and fiscal effects of changes in the fleet mix. Performance and cost characteristics of a fleet option can be displayed for each aircraft type in the mix and changes to the mix will produce related changes in the performance and cost parameters. This format allows the user to see the contribution each aircraft makes to overall performance and cost. The format also highlights the cost of operating older aircraft.

The analysis provides recommendations for fleet options based on aircraft that are normally available to fly. This number excludes consideration of aircraft required for training missions and those in Depot maintenance. Excluding these aircraft indicates how many aircraft are required to satisfy demand, but not how many are required to complete all the Navy's business, which would include training and periodic Depot maintenance periods. Since reliable data regarding these issues was not available for the

newer aircraft, the decision was made to exclude training aircraft and aircraft in Depot maintenance from the study.

The concept of flexibility is introduced in Chapter V. Flexibility is an important aspect of logistics operations, but it is very hard to quantify. The analysis presented in Chapter V reports that flexibility can be increased by attempting to match the fleet mix to the characteristics of the total demand, *i.e.*, provide a fleet with many small aircraft if the demand has a preponderance of small lifts. The cost of a fleet of smaller aircraft is higher than the cost of a fleet of larger aircraft that has the same total capacity. The analysis indicates that the cost of flexibility is higher than the cost of capacity, but it does not provide a quantifiable cost of flexibility.

E. AREAS FOR FURTHER STUDY

Global Demand Data. This study does not provide a comprehensive recommendation for the composition of the entire Navy airlift fleet. The data provided by the sponsor included only lift requests for flights originating and/or terminating in the continental United States (CONUS). The results of an analysis of global demand data will provide a richer output from the models and allow for more meaningful recommendations.

Refined Aircraft Availability Data. As previously mentioned, the inclusion of data relating to aircraft used for training and in Depot maintenance will provide a better answer to the question of how many aircraft are needed to meet all the Navy's transport aircraft requirements.

Consistent Cost Data. It is desirable to have all cost data flow from one reliable, preferably military, source. Commercial data is prone to carry elements that don't apply

to military operations (hangar fees, for example). Identification of all relevant military costs for the new aircraft models will provide an improved cost result.

Assessment of C-130 Requirements. The C-40 provides vastly improved cargo and passenger capabilities over its predecessor, the C-9. If the C-40 is indeed to be used frequently as a cargo hauler, the need for C-130s may be reduced. C-130s have a valuable capability to carry bulky and wheeled cargo and to operate from short and unimproved runways, but are slower than the C-40 and aren't as well suited to passenger operations. A study comparing demand, costs, and capabilities of the C-40 and C-130 could provide richer fleet mix recommendations.

Wartime Demand Data. To provide the most relevant analysis, estimates of wartime demand must be included in determining fleet requirements. It is useful to know what capacity is required to meet peacetime demand, but the logistics fleet must also be capable of providing surge capacity in the event of up to two major theater wars. When calculated, this demand data can easily be plugged into the assessment model so that fleet mix requirements can be estimated.

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APPENDIX A. FLEET MIX MODEL

Future

	C-35	C-37	C-20	C-40	C-130	no match	Total
Missions	10719	4134	2297	5958	1136	142	24386
Lifts	10719	4134	2297	5389	1136	142	23817
Distance	7049765	5827299	4144742	6292658	2598167		
Avg. Distance	658	1410	1804	1168	2287		
FH Req'd	17406.8	13647.1	9506.3	18095.4	10392.7		
Avg. FH/Lift	1.6	3.3	4.1	3.4	9.1		

Hrs/Month	60	75	75	125	60
ρ	85%	80%	80%	75%	55%
FH Av./Mo.	1530	300	360	1406.25	660
FH Av.	41310.0	8100.0	9720.0	37968.8	17820.0
Δ	23903.2	-5547.1	213.7	19873.4	7427.3

No. of Months:	27
No. of Lifts/Mo.:	882

						Total
Acft Needed:	13	9	6	9	12	49
Acft Av.	30	5	6	15	20	76
Acft. Short:	-17	4	0	-6	-8	

Lift Data						
Avg. Pax	3	12	17	55	10	324
Avg. Cargo	6	47	1021	3069	11032	14504
Avg. Load	701	2362	4338	14122	13076	79213

Monthly Data							Liquidated	Total	
Pax Short:	-1856	787	0	-9258	-295	1702	-1702	**-10621**	(Excess)
Cargo Short:	-3270	3225	0	-514166	-318347	76281	-94504	**-850780**	(Excess)
Load Short:	-374469	160723	0	-2365728	-377347	416600	-434822	**-2975045**	(Excess)

Combining C-40 Missions

	C-40	2 X C-40	Combined
Missions	4820	569	5958
Lifts	4820	569	5389
Distance	5510030	782629	6292658
C-40 FH	14092.1	4003.2	18095.4
Pax	251552	77713	329265
Cargo	10885848	7401051	18286899
Load	61196248	22943651	84139899
Avg. FH/Lift	2.9	7.0	3.4
Avg. FH/Msn	2.9	7.0	3.0

Liquidating the "No Match"

C-40 Msns/Mo:	221			
Msns/Acft/Mo:	28			
	no match	Avg. per Msn	Missions	A/C
Pax	1702	55	30.79	1.12
Cargo	76281	3069	24.85	0.90
Load	416600	14122	29.50	1.07
C-40s req'd:				1.12
Prelim. C-40 req.				8
Total C-40s:				**9**

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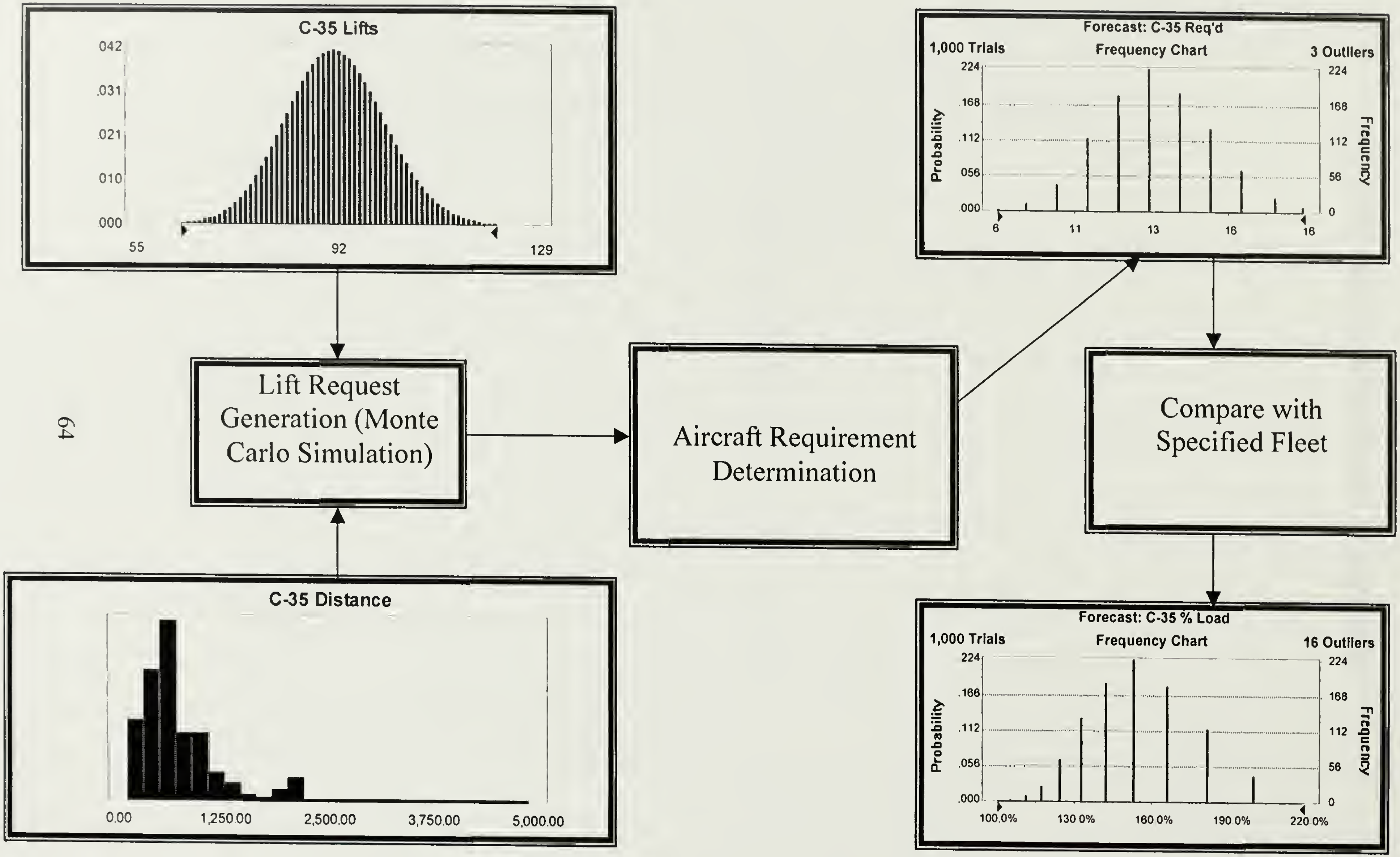
APPENDIX B. STOCHASTIC MODEL PROCESS


C-35 Lifts
042
.031
.021
010
.000
55
92
129
C-35 Distance
0.00
1,250.00
2,500.00
3,750.00
5,000.00
Lift Request Generation (Monte Carlo Simulation)
Aircraft Requirement Determination
Forecast: C-35 Req'd
1,000 Trials
Frequency Chart
3 Outliers
Probability
Frequency
224
.168
.112
.056
.000
6
11
13
16
Compare with Specified Fleet
Forecast: C-35 % Load
1,000 Trials
Frequency Chart
16 Outliers
100.0%
130.0%
160.0%
190.0%
220.0%

APPENDIX C. FLEET MIX CALCULATION RESULTS

Stochastic Fleet Mix Model - Future Fleet

	C-35	C-37	C-20	C-40	C-130	no match
λ	91	35	20	n/a	10.28	1.21
Proj. Lifts	91	35	20	45	10.28	1.21
Cum Distance	60369.4	48811	34143	51929.6	23087	917.4
Speed	405	427	436	391	292	
FH Req'd	149.1	114.3	78.3	102.2	47.4	
α	0%	0%	0%	35%	40%	

FH Av./Mo	60	75	125	125	60	Months:	0.230
ρ	0.85	0.8	0.8	0.75	0.55		
FH Av./Wk	11.7	13.8	23.0	21.6	7.6		

Aggregate C-40			
	C-40	2 X C-40	Combined
λ	40	4.85	
Proj. Lifts	40	4.85	
Cum Distance	46040	5889.6	51929.6
Speed	391	391	391
FH Req'd	117.7	30.1	147.9

Liquidating the "no match" — * - Assuming nearly full capacity on C-40s carrying "no match" loads.

	"no match" avg.	Unmatched	C-40 Cap*	C-40 Msns	Msns Req'd		
Pax	324	392	110	3.56	4	Cum Distance	917.4
Cargo	14504	17556	15000	1.17		Speed	391
Payload	79213	95877	37000	2.59		FH Req'd	9.4
						Total C-40 FH Req'd:	157.3

	C-35	C-37	C-20	C-40	C-130	Totals
Acft Required	13	9	4	5	7	38
Acft Available	15	0	3	11	14	43
Acft Short	-2	9	1	-6	-7	-5

Mission Data						Total
Avg. Pax	3.5	12	17	55	10	
Avg. Cargo	6.1	47	1021	3069	11032	
Avg. Payload	701	2362	4338	14122	13076	
Load for Week	64084	83225	84931	640268	134420	1006928

Weekly Data						Totals	
Pax Short	-49	408	81	-3007	-105	-2672	excess
Cargo Short	-86	1670	4996	-166986	-113403	-273810	excess
Load Short	-9859	83225	21233	-768322	-134420	-808143	excess
% of Load ass.	115.4%	0.0%	75.0%	220.0%	200.0%	180.3%	

APPENDIX D. C-130 LIFE CYCLE COST ANALYSIS

Life Cycle Cost Analysis

All $ Amounts in Millions

A/C Type: C-130
# of old 14
retired 14

Disc. Rate: 4.2%

NPV of LCC: $668.4 (one-cycle)

					Old Aircraft Costs		New Acft Costs		One Cycle LCC (New Acft.)		Inf. Horizon (New Acft.)	
Fiscal Year	# Retired	# Old in Service	# New Purchased	# In Service[1]	Recurring O&M $	FY 2000 O&M $	FY 2000 APN $	FY 2000 O&M $	LCC (FY 2000$)3	One Cycle + Old O&M Cost (FY 2000$)4	Infinite Horizon (FY 2000$)	EANC (FY 2000$)
1	0	14	0	14	$15.4	$15.4	$0.0	$0.0	$0.0	$15.4	$0.0	$0.0
2	0	14	0	14	$15.4	$14.7	$0.0	$0.0	$0.0	$14.7	$0.0	$0.0
3	0	14	0	14	$15.4	$14.1	$0.0	$0.0	$0.0	$14.1	$0.0	$0.0
4	0	14	0	14	$15.4	$13.6	$0.0	$0.0	$0.0	$13.6	$0.0	$0.0
5	0	14	0	14	$15.4	$13.0	$0.0	$0.0	$0.0	$13.0	$0.0	$0.0
6	0	14	0	14	$15.4	$12.5	$0.0	$0.0	$0.0	$12.5	$0.0	$0.0
7	0	14	0	14	$15.4	$12.0	$0.0	$0.0	$0.0	$12.0	$0.0	$0.0
8	0	14	0	14	$15.4	$11.5	$0.0	$0.0	$0.0	$11.5	$0.0	$0.0
9	0	14	0	14	$15.4	$11.0	$0.0	$0.0	$0.0	$11.0	$0.0	$0.0
10	0	14	2	14	$15.4	$10.5	$54.8	$0.0	$80.5	$91.0	$112.4	$4.7
11	2	12	5	14	$13.2	$8.7	$131.4	$0.5	$193.0	$201.6	$269.4	$11.3
12	5	7	2	14	$7.7	$4.8	$50.4	$1.7	$74.0	$78.9	$103.3	$4.3
13	2	5	3	14	$5.5	$3.3	$72.5	$2.1	$106.5	$109.8	$148.6	$6.2
14	3	2	2	14	$2.2	$1.3	$46.3	$2.7	$68.1	$69.3	$95.0	$4.0
15	2	0	0	14	$0.0	$0.0	$0.0	$3.0	$0.0	$0.0	$0.0	$0.0
16	0	0	0	14	$0.0	$0.0	$0.0	$2.9	$0.0	$0.0	$0.0	$0.0
17	0	0	0	14	$0.0	$0.0	$0.0	$2.8	$0.0	$0.0	$0.0	$0.0
18	0	0	0	14	$0.0	$0.0	$0.0	$2.7	$0.0	$0.0	$0.0	$0.0
19	0	0	0	14	$0.0	$0.0	$0.0	$2.5	$0.0	$0.0	$0.0	$0.0
20	0	0		14	$0.0	$0.0	$0.0	$2.4	$0.0	$0.0	$0.0	$0.0
Total:	14		14			$146.4	$355.5	$23.3		$668.4	$728.7	$30.6

Total FY2000$2: $525.2

Notes: 1. Aircraft purchased in year X enter service in year X + 1.
2. Old O&M + New APN + New O&M.
3. The NPV of purchasing and operating the new aircraft through one life cycle.
4. Previous column plus O&M cost from old aircraft.

APPENDIX E. LIFE CYCLE COST CALCULATION RESULTS

Assuming all purchased in Year 1:

Type	# Purch.	One Cycle LCC (per aircraft)	Infinite Horizon LCC (per aircraft)	NPV of One-Cycle LCC	NPV of Infinite Horizon LCC	EANC1
C-12	0	$9.78	$17.21	$0.00	$0.00	$0.00
C-35	17	$14.93	$26.26	$253.74	$446.50	$18.75
C-37	2	$52.85	$92.99	$105.69	$185.99	$7.81
C-20	11	$43.00	$75.67	$473.00	$832.32	$34.96
C-40	9	$92.66	$129.35	$833.94	$1,164.16	$48.89
C-130	14	$58.74	$82.00	$822.35	$1,147.99	$48.22
Total:	**53**			**$2,488.73**	**$3,776.95**	**$158.63**

Assuming spread out acquisition and retirement:

Type	# Purch.	NPV of Old O&M	NPV of One Cycle LCC	NPV of Infinite Horizon LCC	EANC1
C-12	0	$34.33	$34.33	$0.00	$0.00
C-35	17		$230.41	$405.44	$17.03
C-37	2		$103.52	$182.16	$7.65
C-20	11	$18.38	$449.28	$758.25	$31.85
C-9	0	$57.35	$57.35	$0.00	$0.00
C-40	9		$775.12	$1,082.05	$45.45
C-130	14	$146.36	$668.35	$728.69	$30.61
Total:	**53**	**$256.42**	**$2,284.04**	**$3,156.60**	**$132.58**

Notes: 1. EANC applies only to newly acquired aircraft.

APPENDIX F. COMPARISON OF FLEET MIX OPTIONS

Current Fleet Mix

	C-12	C-20	C-9	C-130	Fleet
# of planes	27	3	12	14	56
μ	113%	34%	199%	219%	161%
P(C>=100)	0.83	0.01	0.92	0.968	0.91
P(C>=150)					0.59
P(C>=200)					0.17

All amounts in FY 2000 $M

Option A: Future Fleet w/Similar Inventory

	C-35	C-37	C-20	C-40	C-130	Fleet
# of planes	27	0	3	12	14	56
μ	208%	0%	83%	217%	236%	185%
P(C>=100)	1.00	0.00	0.35	1.00	0.99	1.00
P(C>=150)						0.86
P(C>=200)						0.29

EANC		NPV of O&M
Basic	Enhanced	
$153	$123	$302

Option B: Future Fleet w/Similar Performance

	C-35	C-37	C-20	C-40	C-130	Fleet
# of planes	15	0	3	11	14	43
μ	115%	0%	80%	199%	238%	168%
P(C>=100)	0.9	0	0.32	1	0.99	1
P(C>=150)						0.7
P(C>=200)						0.15

EANC Basic	EANC Enhanced	NPV of O&M
$134	$108	$263

Option C: Future Fleet w/Focus on Increased Capacity

	C-35	C-37	C-20	C-40	C-130	Fleet
# of planes	15	0	3	14	14	46
μ	116%	0%	82%	253%	236%	202%
P(C>=100)	0.90	0.00	0.35	1.00	0.99	1.00
P(C>=150)						0.93
P(C>=200)						0.50

EANC Basic	EANC Enhanced	NPV of O&M
$150	$121	$283

Option D: Future Fleet w/Focus on Increased Flexibility

	C-35	C-37	C-20	C-40	C-130	Fleet
# of planes	17	6	7	9	14	53
μ	131%	72%	191%	164%	243%	162%
P(C>=100)	0.99	0.12	1	0.95	0.99	0.99
P(C>=150)						0.64
P(C>=200)						0.1

EANC Basic	EANC Enhanced	NPV of O&M
$161	$136	$263

APPENDIX G. SAMPLE PROCUREMENT AND RETIREMENT SCHEDULE

Year	C-12		C-35		C-37		C-20		C-9		C-40		C-130	
	Retired	Purch.	Retired	Purch.	Retired	Purch.	Retired	Purch.	Retired	Purch.	Retired	Purch.	Retired	Purch.
1				3		1		2	2			2		
2	6			3		1		2	2			2		
3	6			3				2	2			2		
4	6			3				2	2			2		
5	5			3				2	2			1		
6	4			2			2	1	2					
7							1							
8														
9														
10														2
11													2	5
12													5	2
13													2	3
14													3	2
15													2	
16														
17														
18														
19														
20														
Total:	27	0	0	17	0	2	3	11	12	0	0	9	14	14

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